Chapter 11
PATH: Hatchery Impacts

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Summary

This chapter is composed of three sections. Section 1 contains a list of management actions and hypotheses about the effects of hatchery fish on wild populations. The hypotheses are intended to be helpful in answering both retrospective and prospective management questions about consequences of and opportunities for artificial propagation. In the chapter, several methods are applied to demonstrate how hypotheses might be tested with available information.

Evidence from the literature is presented for some hypotheses in Section 1, categorized (in a very preliminary exercise) as to whether each citation tends to support or refute the hypothesis, or indicates whether the effect described has a positive or negative impact on affected populations. In Section 2, several hypotheses tests are used to evaluate the effectiveness of two hatchery programs in increasing overall juvenile survival. Section 3 presents an example of a quantitative approach to testing hypotheses about the impacts hatchery fish have had on naturally spawning stocks.

In the Discussion section at the end of the chapter, plans for completing the analyses included in the chapter are presented, along with some decision points on how the analyses might proceed. The intent is to elicit comments from reviewers. Plans and decision points for comment also appear in method, results, and discussions in the three main sections.

11.1. Draft Approach to Hatchery Hypotheses and Evaluation of Evidence

Hypotheses and management questions have been reorganized to the extent possible, per Carl Walters' suggestion, into two basic categories related to future experimental design opportunities: (a) questions about within-stock consequences of rearing part or all of the fish under hatchery conditions, and (b) questions about between-stock consequences of competition, straying of hatchery fish, diseases transmission, etc. As agreed in a May meeting of the hatchery subgroup, hypothesis wording and evidence organization have also been revised to present evidence for positive effects vs. evidence for negative effects, for hypotheses where the question of whether or not there is some impact is not at issue.

A first attempt at listing literature evidence addressing each hypothesis is presented. For the most part, only the citations are presented. The evidence description format will need to be expanded to include more than comments on the strengths and weaknesses. We need to have wording indicating exactly what the relevant evidence or conclusion is from each paper, or at least categorize the evidence by mechanism implied, for those hypotheses where more than one mechanism can bear upon on the effect in question. A couple of questions to keep in mind when reviewing the hypotheses below:

1. Some of the hypotheses are still not framed in positive effect / negative effect fashion. Some of these could potentially be re-framed in positive/negative style, but it would take substantial

rewording and alter the resolution and intent of the hypotheses (e.g. the hypotheses about competition from hatchery-produced fish affecting wild fish). Obviously, competition for food can only have a negative effect on survival. However, these hypotheses could be reformed in a broader wording that would ask only whether wild fish survival in freshwater or the ocean is increased or decreased by hatcheries. The hypotheses would subsume several mechanisms, most notably competition and predation.

2. Between-stock hypotheses 3 and 4 might be getting at the same question. Number 4 asks if removal of naturally produced adults for hatchery broodstock has reduced wild population size. At one level, the answer to the question is obvious: yes, since it removes fish that would otherwise spawn in the wild, it decreases wild population size, if this is equated to number of wild spawners. But what we really want to know is, I think, is it better for the wild runs in the long run if we continue (or start) to take wild spawners into the hatchery. This question is pretty much what hypothesis 3 is addressing, I believe. Can and should these two hypotheses be merged into one question, and evidence arranged accordingly?

11.1.1 Management Questions

Within-Stock Impacts

1. What characteristics (e.g. at what level of measurable genetic differentiation, or how many generations or what degree of hatchery lineage) confer “hatchery” status on a fish, so that it is no longer considered “native” (e.g. no longer a part of a listed ESU)? How do we distinguish whether a desirable event (supplementation) or a largely undesirable event (straying) has occurred, when a hatchery-produced fish spawns in the wild?

2. What is the likely impact on long-term fitness in target and non-target populations resulting from particular supplementation strategies? Alternatively, how have hatchery programs affected (and how can they be expected in the future to affect) within-population and between-population genetic variability?

3. How can selection for traits that are maladaptive in the wild be minimized in the hatchery?

4. Can “remedial selection” or outbreeding in a hatchery ever be safely employed on stocks that have already lost genetic variability or are poorly adapted to a modern environment?

5. When supplementing a severely depressed natural stock, what proportion (or number) of returning spawners should be allowed to spawn naturally, as an insurance policy against catastrophe in the hatchery, and given genetic considerations (variance in reproductive success)?

6. Has artificial production altered average generation length in wild stocks? If so, how, and what are the consequences to wild stocks? If consequences are negative, can this impact be eliminated by modifying hatchery practices?

7. What portion of historic production can be sustained by hatchery programs where natural recruitment processes are inadequate to do so?

8. At what point (measured by absolute escapement or trend in escapements) should captive breeding be initiated in an attempt to prevent extirpation of an endangered stock?

9. By what measures can the success of existing or former hatchery programs (supplementation or augmentation) be assessed? What data should be gathered and what criteria used to gauge performance in the future?

Between-Stock Effects

1. What characteristics (e.g. at what level of measurable genetic differentiation, or how many generations or what degree of hatchery lineage) confer "hatchery" status on a fish, so that it is no longer considered "native" (e.g. no longer a part of a listed ESU)? How do we distinguish whether a desirable event (supplementation) or a largely undesirable event (straying) has occurred, when a hatchery-produced fish spawns in the wild?

2. What is the extent of straying from hatcheries to non-target streams, and what are the ecological and genetic consequences for wild stocks?

3. What are the consequences of using non-native brood stock to supplement a depressed population?

4. What is the appropriate level or scale of supplementation for an ESU composed of largely isolated breeding units (e.g. Snake R. spring/summer chinook)?

5. What is the likely impact on long-term fitness in target and non-target populations resulting from particular supplementation strategies? Alternatively, how have hatchery programs affected (and how can they be expected in the future to affect) within-population and between-population genetic variability?

6. What combinations of release size, time, location, and density of target (listed) species (supplementation program) will stimulate natural production without displacing wild fish?

7. What combinations of release size, time, and density of non-target (non-listed) species will meet hatchery goals without negatively affecting listed species?

8. What magnitudes or strategies employed by particular supplementation projects will avoid attracting predators and exacerbating predatory losses of wild fish?

9. What are the impacts of hatchery effluent on water quality, and how does this affect wild stocks?

10. What is the incidence of vertical transmission of disease from hatchery to wild fish, and what is the impact of such transmission?

11. Given the harvest regulations in place, how does artificial propagation in the Columbia Basin affect in-river and ocean fishing mortality on listed stocks?

12. Under current and planned propagation projects, how could harvest regulation be modified to minimize fishing mortality on listed stocks?

13. How should production at various Columbia basin hatcheries be prioritized, given NMFS's suggested production cap and ESA needs?

14. How have management decisions regarding downstream passage (e.g. timing of water releases), based primarily on hatchery fish, affected wild fish?

15. What portion of historic production can be sustained by hatchery programs in conjunction with harvest reduction and habitat improvement?

16. By what measures can the success of existing or former hatchery programs (supplementation or augmentation) be assessed? What data should be gathered and what criteria used to gauge performance in the future?

11.1.2 Hypotheses

Within-Stock Effects

1. Supplementation projects have altered effective population size of supplemented populations.

Evidence for positive effect (increase)	Strengths of Evidence	Weaknesses of Evidence
Ryman et al. 1995	For successful supportive breeding, probability of allele retention generally increases. Variance effective size may increase. Theoretical, generally applicable.	Variance effective size may decrease. Inbreeding effective size always decreases. Theoretical, not empirical evidence.
Hindar et al. 1991	(survey)	(survey)
Hedrick et al. 1995		

Evidence for negative effect (decrease)	Strengths of Evidence	Weaknesses of Evidence
Mork 1991		
Ryman and Stahl 1980		
Simon et al. 1986		
Garcia-Marin et al. 1991		
Ryman et al. 1995	Inbreeding effective number always reduced. Variance effective size may decrease, as well.	Probability of allele retention generally increases. Variance effective size may increase
Ryman and Laikre 1991		
Ryman 1981		
Stahl 1983		
Allendorf and Phelps 1980		
Hindar et al. 1991	(survey)	(survey)

2. Supplementation programs and strays from augmentation hatcheries have altered population fitness of affected fish in the wild.

Evidence for positive effect	Strengths of Evidence	Weaknesses of Evidence
Johnsson and Abrahams 1991		

Evidence for negative effect	Strengths of Evidence	Weaknesses of Evidence
Gharret and Smoker 1991		

Fleming and Gross 1993, Fleming and Gross 1992		
Keifer and Forster 1992		
Steward and Bjornn 1992	(survey)	(survey)
Swain and Riddell 1990		
Steward and Bjornn 1990	(survey)	(survey)
Fleming and Gross 1989		
Nickelson et al. 1986		
Allendorf and Ryman 1987		

3. Artificial propagation has altered time of spawning (within season) of wild stocks, by selectively breeding fish returning in only one segment of the spawning period, in conjunction with spawning of these time-selected hatchery fish in native habitat.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
Leary et al. 1989		
Garrison and Rosentreter 1981		
Waples 1991		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence

4. Artificial propagation has resulted in a shift of spawner age distribution of affected naturally spawning populations toward younger ages; i.e. it tends to decrease generation length.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
Messmer et al. 1993		
Olson et al. 1993 and Olson unpublished data		
Hankin et al. 1993		
Gross 1991		
Van den Berghe and Gross 1984		
Bjornn 1978		
Hankin and McKelvey 1985		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence

Between-Stock Effects

1. Hybridization of strays from production hatcheries with native fish has altered effective population size and fitness of the wild populations.

Evidence for positive effect (e.g. heterosis, increased N_e)	Strengths of evidence	Weaknesses of evidence
Kapuscinski and Lannan 1984		

Evidence for negative effects	Strengths of Evidence	Weaknesses of Evidence

(e.g. outbreeding depression, non-locally adapted alleles)		
Gharret and Smoker 1991		
Hindar et al. 1991	(survey)	(survey)
Steward and Bjornn 1990	(survey)	(survey)
Emlen 1991		
Allendorf and Leary 1988		
Reisenbichler 1988		
Reisenbichler and McIntyre 1977		
Quinn et al. 1991		
McIsaac and Quinn 1988		
Quinn and Fresh 1984		
Wade 1986		

2. Supplementation of small wild stocks with non-native donor stock has altered the genetic character and affected fitness of the wild stocks.

Evidence for positive effect (e.g. heterosis)	Strengths of Evidence	Weaknesses of Evidence
Steward and Bjornn 1990	(survey)	(survey)
Kapuscinski and Lannan 1984		

Evidence for negative effect (e.g. outbreeding depression)	Strengths of Evidence	Weaknesses of Evidence
Allendorf and Leary 1988		
Hindar et al. 1991	(survey)	(survey)
Steward and Bjornn 1990	(survey)	(survey)
Reisenbichler 1988		
Emlen 1991		
Reisenbichler and McIntyre 1977		
Quinn et al. 1991		
McIsaac and Quinn 1988		
Quinn and Fresh 1984		
Wade 1986		

3. Supplementation, by circumventing much human-induced mortality, has contributed to meta-population stability (and has helped maintain genetic diversity) by allowing sub-populations to persist in damaged habitat (hatcheries have acted as gene banks for some native populations).

Evidence For	Strengths of Evidence	Weaknesses of Evidence

4. Removal of fish produced through natural spawning for hatchery broodstock has contributed to decline of wild donor stocks. *Alternative wording*: Removal of wild adults for use as hatchery broodstock has resulted in a net (increase/decrease) in the numbers of naturally spawning fish.

Evidence for decrease	Strengths of Evidence	Weaknesses of Evidence

Evidence for increase	Strengths of Evidence	Weaknesses of Evidence

5. Transfer of fish between hatcheries combined with outplanting and straying has altered the amount of genetic diversity between populations comprising listed ESUs.

Evidence for positive or no effect (maintenance of diversity)	Strengths of Evidence	Weaknesses of Evidence

Evidence for negative effect (loss of diversity)	Strengths of Evidence	Weaknesses of Evidence
Mork 1991		
Garcia-Marin et al. 1991		
Hindar et al. 1991	(survey)	(survey)
Reisenbichler and Phelps 1989		
Allendorf and Leary 1988		
Stahl 1983		
Ryman 1981		

6. Hatchery effluent has altered growth and survival of wild fish downstream.

Evidence for positive effects (e.g. through increased productivity)	Strengths of Evidence	Weaknesses of Evidence
Kendra 1991		

Evidence for negative effects (degraded water quality through temperature, pH, etc.)	Strengths of Evidence	Weaknesses of Evidence
Kendra 1991		

7. Artificial propagation has resulted in disease transmission (e.g. during transportation, from effluent) to wild fish.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
NMFS 1993		
Hastein and Lindstad 1991		
Saunder 1991		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence

8. Stocking of hatchery-reared fish has altered inter-specific predation mortality on wild fish in rearing and freshwater migratory habitat.

Evidence for positive effect (decreased mortality, e.g. due to depensation)	Strengths of Evidence	Weaknesses of Evidence

Evidence for negative effect (increased mortality - predator attraction)	Strengths of Evidence	Weaknesses of Evidence
Peterman and Gatto 1978		
Peterman 1987 (?)		
Steward and Bjornn 1992	(survey)	(survey)
Steward and Bjornn 1990	(survey)	(survey)

9. High system-wide levels of artificial production have altered mortality from inter-specific predation on wild smolts in the estuary.

Evidence for positive effect (decreased mortality - depensation)	Strengths of Evidence	Weaknesses of Evidence

Evidence for negative effect (increased mortality - predator attraction)	Strengths of Evidence	Weaknesses of Evidence

10. Inter-specific predation by hatchery fish on wild juveniles (e.g. residualized steelhead in upper migration corridor of Snake R. may prey on newly emergent chinook) is a significant source of mortality in some stocks.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
USFWS 1992		
Cannamela 1993		
NMFS 1993		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence
NMFS 1993		
Whitesel et al. 1994		

11. Predation by hatchery smolts has resulted in significant mortality on smaller wild con-specific juveniles in some stocks.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
Steward and Bjornn 1992	(survey)	(survey)
Steward and Bjornn 1990	(survey)	(survey)

Evidence Against	Strengths of Evidence	Weaknesses of Evidence
USFWS 1992		

12. Artificial propagation has resulted in displacement and decreased survival of wild fish, due to **intra-** specific competition for space and food in freshwater juvenile life stage.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
Steward and Bjornn 1992	(survey)	(survey)
Steward and Bjornn 1990	(survey)	(survey)
Smith et al. 1985		
Bjornn 1978		
Nickelson et al. 1986		
Muir and Coley 1994		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence

13. Artificial propagation has resulted in displacement and decreased survival of wild fish, due to **inter-** specific competition for space and food in freshwater juvenile life stage.

Evidence For	Strengths of Evidence	Weaknesses of Evidence

Evidence Against	Strengths of Evidence	Weaknesses of Evidence

14. High system-wide levels of artificial production subject wild fish to competition from hatchery fish for food in the ocean and estuary, reducing their survival.

Evidence For	Strengths of Evidence	Weaknesses of Evidence
Fagen and Smoker 1989		
Peterman and Routledge 1983		
Peterman 1984		
Emlen et al. 1990		
Steward and Bjornn 1990	(survey)	(survey)
Neilson et al. 1985		
McCarl and Rettig 1983		

Evidence Against	Strengths of Evidence	Weaknesses of Evidence
Nickelson 1986		
Levings et al. 1986		
Steward and Bjornn 1990	(survey)	(survey)

15. High system-wide levels of artificial production have altered mortality from inter-specific predation on returning wild adults in the estuary.

Evidence for positive effect (decreased mortality - depensation)	Strengths of Evidence	Weaknesses of Evidence

Evidence for negative effect (increased mortality - predator attraction)	Strengths of Evidence	Weaknesses of Evidence

16. Artificial propagation has altered the probability that a wild fish will be caught in a fishery, and therefore altered the fishing mortality on wild stocks.

Note: Whether wild fish F decreases or increases depends on whether the fishery is managed for a harvest quota, or whether hatcheries increase total effort and in the process effort on wild fish.

Evidence for positive effect (decreased F)	Strengths of Evidence	Weaknesses of Evidence

Evidence for negative effect (increased F)	Strengths of Evidence	Weaknesses of Evidence
Lestelle and Gilbertson 1993 (ocean and Columbia R.)		Fall chinook only

11.1.3 Literature Cited for Hatchery Hypotheses

This reference list is intended to elicit comments on the usefulness of specific papers, prompt readers to suggest sources which have been overlooked, and help me obtain copies of references I haven't yet seen. Some of the papers are cited through third party interpretations of their conclusions and the evidence presented in them; i.e., I haven't read them. Not all of the papers here have been cited in the hypothesis evidence above. References in bold typeface are papers I have not seen, and would like to get a copy of.

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In addition, these talks were presented at recent sustainable fisheries conference. Does anyone know if papers are in preparation (or have been published) for these talks?

Do Artificially Reared Pacific Salmon Have an Impact on Wild Salmon in the Ocean? R. Beamish et al., DFO.

The Effects of Releases of Hatchery-Reared Steelhead on Wild Salmonids in Natural Streams: Geoffrey A. McMichael, Todd N. Pearsons, and Steven A. Leider - Washington Department of Fish and Wildlife.

An Overview of the State of Washington's Wild Salmonid Policy: Richard W. Stone - Washington Department of Fish and Wildlife.

Genetic Considerations in Captive Breeding to Supplement a Threatened Population: Milo D. Adkison and Ray Hilborn.

11.2 Comparison of Wild and Hatchery Progeny-to-Parent Ratios Draft Pilot Study

11.2.1 Introduction

Supplementation of endangered, threatened, or otherwise depressed wild salmon and steelhead stocks in the Columbia River basin is already in progress and may be instituted in the future in stocks not previously subject to it (e.g., CBFWA 1991). Supplementation for conservation purposes involves releasing fish propagated artificially into or near streams where natural spawning occurs, in the hope that some artificially produced adults and/or their progeny will spawn naturally and eventually become integrated with and increase the size of the naturally spawning population. The most desirable form of supplementation for rehabilitation of stocks listed under the Endangered Species Act has been referred to as “internal supplementation” (Cuenco 1994) or “supportive breeding” (Ryman and Laikre 1991). This process involves using as broodstock fish native to the stream being supplemented (or fish from nearby streams, supposedly closely related and sharing genetic and life-history characteristics with the target stock). The idea is to use artificial spawning and rearing (to release at some juvenile life stage) to increase the overall survival to adult of the artificially bred fish above that of naturally spawned fish.

Increasing the spawning size of a listed population through supportive breeding can be expected to have numerous salutary effects, especially in the short term. A number of potential disadvantages have also been hypothesized about the long-term effects of such programs, even if they are successful at their intended goal of increasing survival and naturally spawning population size. These benefits and drawbacks are discussed elsewhere in this chapter. To be considered successful, however, a supportive breeding program must at least increase the survival of progeny of adult fish brought into the hatchery over the survival they would experience if their parents were allowed to spawn in the wild. Data on artificial salmon and steelhead production programs that have been operated as conservation hatcheries, or that have been operated in a manner similar to supportive breeding programs in key aspects, may provide evidence useful in predicting whether this minimum requirement of a supportive breeding program is likely to be met. In the Columbia basin, there are several stocks of anadromous salmonids which have histories of hatchery supplementation along with data on performance of both hatchery and naturally produced fish which make them candidates for this analysis.

11.2.2 Methods

Data Sources

There are two cases in the Columbia basin which closely match the desired conditions of having been operated like supportive breeding programs in key respects, and where wild and hatchery recruit-per-spawner data were available in time to include in this report. Other cases in the basin will be explored for their potential to be included in future versions of this report. A useful measure of the relative utility of internal supplementation in increasing production and population size is the number of recruits produced by a spawning aggregate, divided by the number of spawners.

Comparison of this quotient between hatchery and wild spawners should allow determination of whether a hatchery has produced more adults per spawner than natural spawning and rearing.

The first case involves the Warm Springs National Fish Hatchery (NFH), which is operated by the U.S. Fish and Wildlife Service, and the naturally spawning population of spring chinook salmon in the Warm Springs River, Oregon. Artificial propagation of spring chinook began in brood year 1978, with the goal of augmenting harvest without negatively impacting wild fish. From 1958 to 1972, some non-indigenous fish were planted in the Warm Springs (Olson et al. 1995). The broodstock in the first four years of the production program was comprised entirely of wild chinook collected in the Warm Springs River. In most subsequent years, both artificially- and naturally-produced spawners were used as hatchery broodstock. Hatchery juveniles are released as both subyearlings in the fall and as yearlings in the spring; both forced and volitional releases occur. The history of the program and facilities are described in Olson et al. (1995). Data on production from naturally spawning fish in the Warm Springs are from Beamesderfer et al. (1996). Estimates of spawners and recruits to the mouth of the Columbia River (to include fish harvested inriver) by year are available from brood year 1969 to 1990.

To estimate hatchery recruits to the mouth of the Columbia River, I used data from Olson et al. (1995) and D. Olson (USFWS, unpublished data) on broodstock take and age 3, 4, and 5 recruits to the mouth of the Deschutes River (to which the Warm Springs is tributary) for each brood. The data allow estimation of R/S ratios for recruits to the mouth of the Columbia River for brood years 1978-1990. I adjusted Deschutes recruit numbers of each age by expanding for estimated spring chinook dam conversion rate from Beamesderfer et al. (1996) for the appropriate run year for the two Columbia River dams that the fish migrate through. These numbers for each age were then expanded to account for Columbia River harvest by using estimates of spring chinook harvest rates for the appropriate years (Beamesderfer et al. 1996). For each year's hatchery "spawners", I used adults collected and kept that year. This number was different than the number of fish actually spawned, but includes all consumptive use of adults and reflects the actual loss to natural spawning due to the hatchery program. Prior to 1992, no three year-olds were kept for hatchery broodstock (D. Olson, pers. comm.).

The second program analyzed in this paper is the supplementation of Imnaha River, Oregon, spring/summer chinook with spring chinook from ODFW's Lookingglass Hatchery. The hatchery was established as part of the Lower Snake River Compensation Plan (LSRCP), to compensate for losses to salmon and steelhead in the Grande Ronde and Imnaha River basins incurred when the lower Snake River dams were built. Since the initiation of the program in 1982, the broodstock used to supplement the Imnaha has been entirely comprised of fish returning to the Imnaha River (R. Carmichael, pers. comm.).

Data used in this analysis are parent-to-progeny ratios for natural fish and hatchery fish for brood years 1982-1990, calculated by ODFW and provided by R. Carmichael (pers. comm.). These ratios are estimates of progeny returning to the spawning grounds (or hatchery) divided by estimates of the parent spawning stock that produced them. The same nine years of hatchery data were available for another supplemented stock under the LSRCP, Little Sheep Creek summer steelhead. However, only the last three complete brood years have been reconstructed for the natural stock, so these data were not used in the analysis. The Imnaha R. hatchery progeny-to-parent ratios are derived from weir counts and do not include harvested fish in the progeny, so the ratio estimates recruits to the hatchery divided by the number of fish kept for the hatchery broodstock that produced them. Ratios for Imnaha R. naturally spawning fish are based on redd counts on spawning grounds, and also do not include harvested fish; the ratio estimates recruits to the spawning grounds divided by the number of spawners that produced them. Details of program objectives, release histories and survival estimation can be found in ODFW progress reports on evaluation of LSRCP facilities (e.g. Messmer et al. 1993). Data on production from naturally spawning fish in the Imnaha can be found in Beamesderfer et al. (1996). Estimates of spawners and recruits by year are available from brood year 1949 to 1990, with the exception of brood year 1951.

Hypothesis Testing

Tests were performed on hypotheses regarding the difference between the population variances and means. Two indices of survival were used in the tests: 1) the untransformed progeny-to-parent or recruit-to-spawner (R/S) ratios; 2) ln(R/S). Testing the second index is analogous to testing for differences between the geometric means of the two R/S time series for each program. The geometric mean of a time series of survivals is a better indicator of the consequences of that series of survivals on the populations than the arithmetic mean (e.g. Peterman 1981).

An F-test (variance ratio test - Zar 1984) was used to compare variances between the two series of indices for both supplementation programs, to determine whether hatchery and wild year-to-year survivals were equally variable or if they were more variable under one method of production than the other. Testing of the means was done in two ways for each index. The two time series of data for each program can be considered to represent a special case of a randomized block design, with a treatment and control and the number of blocks equal to the number of years in the time series. Hypotheses about the equivalence of the means can then be tested using a paired difference test. This test is more appropriate and powerful than a two-sample t-test of the null hypothesis of equivalence of the two means, since that test requires that the two population samples be independent and random (Zar 1984). Hatchery and wild fish from the same stream and brood year can be expected to experience similar freshwater and ocean conditions after release of the hatchery fish into the wild, so hatchery and wild survival rates for the same brood year should not be assumed to be independent. Both one- and two-tailed tests were performed.

Although the paired-difference t-test does not require normality and equality of variances assumptions on the original data (R/S or ln(R/S)) for this study, it does require that the sample differences come from a normally distributed population of differences (Zar 1984). To allow for the possibility that this assumption is violated, two nonparametric tests were also performed for hypotheses about each of the means. The first is the sign test, and the second is the Wilcoxon signed rank test for a paired sample, both described in Zar (1984). The Wilcoxon test is more powerful, but has an underlying assumption that the sampled population is symmetrical about the median (Zar 1984), while the sign test requires no assumptions other than that the pairing of data points is appropriate. Only two-tailed tests were performed for these two tests; one-tailed tests can be performed for later versions of this paper.

11.2.3 Results

Recruits-per-Spawner Ratios

The R/S and ln(R/S) estimates for hatchery and wild fish for Warm Springs are shown in Table 11-1; “R/S” (spawner-to-spawner) values for Imnaha River are shown in Table 11-2.

Table 11-1: R/S for Warm Springs NFH and natural spawners.

Brood Year	Wild R/S	Hatchery	Ln(Wild R/S)	Ln(Hatchery

		R/S		R/S)
1978	1.966	4.652	0.676	1.537
1979	4.009	1.199	1.389	0.181
1980	7.312	3.849	1.990	1.348
1981	7.002	4.214	1.946	1.438
1982	4.489	0.342	1.502	-1.074
1983	4.056	2.053	1.400	0.719
1984	4.019	1.879	1.391	0.631
1985	4.252	6.648	1.447	1.894
1986	4.056	4.493	1.400	1.502
1987	1.688	1.848	0.523	0.614
1988	2.856	2.156	1.050	0.768
1989	0.875	0.243	-0.133	-1.416
1990	0.552	0.042	-0.594	-3.173
Mean	3.626	2.586	1.076	0.382
Variance	4.243	4.091	0.586	2.111

Table 11-2: R/S for Imnaha River natural spawners and outplants from Lookingglass Hatchery.

Brood year	Wild R/S	Hatchery R/S	Ln(Wild R/S)	Ln(Hatchery R/S)
1982	1.303	0.536	0.265	-0.624
1983	2.526	0.393	0.927	-0.934
1984	0.546	0.923	-0.605	-0.080
1985	0.468	0.548	-0.759	-0.601
1986	0.409	0.847	-0.894	-0.166
1987	0.358	3.569	-1.027	1.272
1988	0.573	8.955	-0.557	2.192
1989	0.9	5.054	-0.105	1.620
1990	0.345	0.303	-1.064	-1.194
Mean	0.825	2.348	-0.425	0.165
Variance	0.502	8.910	0.445	1.486

Variance Tests

Tests for differences in population variances are presented below. The null hypothesis, H_0, in each instance is that the population variance of the population with the greater sample variance (population 1) is less than or equal to the population variance of the other population (population 2). The alternative hypothesis (H_A) is that the population variance of population 1 is greater than the population variance of population 2. Results are presented in Tables 11-3 to 11-6.

Table 11-3: One-tailed variance ratio test for Warm Springs R/S.

F-Test Two-Sample for Variances
Wild as pop 1

	Wild R/S	*Hatchery R/S*
Mean	3.6256	2.5859
Variance	4.2430	4.0905
Observations	13	13
df	12	12
F	1.03727	
P(F<=f) one-tail	0.47525	
F Critical one-tail	2.68663	

Table 11-4: One-tailed variance ratio test for Warm Springs Ln(R/S).

F-Test Two-Sample for Variances
Hatchery as pop 1

	Hatchery R/S	*Wild R/S*
Mean	0.38239	1.075851
Variance	2.1114	0.586324
Observations	13	13
df	12	12
F	3.60108	
P(F<=f) one-tail	0.01757	
F Critical one-tail	2.68663	

Table 11-5: One-tailed variance ratio test for Imnaha R/S.

F-Test Two-Sample for Variances
Hatchery as pop1

	Hatchery	*Natural*
Mean	2.347556	0.825333
Variance	8.909593	0.502231
Observations	9	9
df	8	8
F	17.74003	
P(F<=f) one-tail	0.000249	
F Critical one-tail	3.438103	

Table 11-6: One-tailed variance ratio test for Imnaha Ln(R/S).

F-Test Two-Sample for Variances
Hatchery as pop 1

	Hatchery	*Natural*
Mean	0.165048	-0.42454
Variance	1.485868	0.444698
Observations	9	9
df	8	8
F	3.341299	
P(F<=f) one-tail	0.05383	
F Critical one-tail	3.438103	

For the Warm Springs stocks, the two indices give similar conclusions, though the R/S test is much less powerful. For R/S, the test fails to reject the null hypothesis that the population with the larger sample variance (wild stock) does not have a larger population variance than the other population (p = .475). It also fails to reject the alternate null hypothesis [Var(R/S_{hat}) >= Var(R/S_{wild})] (p = 1 - .475 = .525). For Ln(R/S), the hypothesis that the hatchery variance is greater is accepted at the 5 percent significance level (p = .024). The Ln(R/S) test is likely the better indicator of relative variability of the two populations, since the variance ratio test is severely and adversely affected by sampling nonnormal populations (Zar 1984). A time series of survivals is likely to exhibit a lognormal error structure (Peterman 1981); the natural log of the survival estimates therefore will better approximate a normal distribution than the survival estimates themselves.

In the Imnaha tests, the hypothesis that hatchery variance in R/S is greater than wild variance is accepted with high significance (p = .00025). The Ln(R/S) is not quite significant at the 5 percent level (p = .054). This test is likely the better indicator, for the reasons described above.

Parametric Paired Difference Tests on the Means

Results of tests for differences in means of the two indices for each stock are presented in Tables 11-7 to 11-10.

Table 11-7: Paired t-test on Warm Springs R/S.

t-Test: Paired Two Sample for Means

	Hatchery R/S	*Wild R/S*
Mean	2.585921	3.6255546
Variance	4.090524	4.2429715
Observations	13	13
Pearson Correlation	0.462835	
Hypothesized Mean Difference	0	
df	12	
t Stat	-1.77155	
P(T<=t) one-tail	0.050919	
t Critical one-tail	1.782287	
P(T<=t) two-tail	0.101838	
t Critical two-tail	2.178813	

Table 11-8: Paired t-test on Warm Springs Ln(R/S).

t-Test: Paired Two Sample for Means

	Hatchery Ln(R/S)	*Wild Ln(R/S)*
Mean	0.382388	1.0758514
Variance	2.111403	0.5863244
Observations	13	13
Pearson Correlation	0.729749	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.41283	
P(T<=t) one-tail	0.016372	
t Critical one-tail	1.782287	
P(T<=t) two-tail	0.032743	
t Critical two-tail	2.178813	

Table 11-9: Paired t-test on Imnaha R/S.

t-Test: Paired Two Sample for Means

	Hatchery R/S	*Natural R/S*
Mean	2.347556	0.825333
Variance	8.909593	0.502231
Observations	9	9
Pearson Correlation	-0.21141	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.42249	
P(T<=t) one-tail	0.096341	
t Critical one-tail	1.859548	
P(T<=t) two-tail	0.192683	
t Critical two-tail	2.306006	

Table 11-10: Paired t-test on Imnaha Ln(R/S).

t-Test: Paired Two Sample for Means

	Hatchery Ln(R/S)	*Natural Ln(R/S)*
Mean	0.165048	-0.42454
Variance	1.485868	0.444698
Observations	9	9
Pearson Correlation	-0.18052	
Hypothesized Mean Difference	0	
df	8	
t Stat	1.186026	
P(T<=t) one-tail	0.13482	
t Critical one-tail	1.859548	
P(T<=t) two-tail	0.26964	
t Critical two-tail	2.306006	

For the Warm Springs example, the R/S one-tail test that wild R/S is greater is almost significant at the 95 percent level (p = .0509). The two-tailed test that the two are different is nearly significant at the 10 percent level (p = .102). The Ln(R/S) test more strongly supports the hypothesis that the wild survival is greater than the hatchery survival (p = .0164 for one-tailed test). In the Imnaha, results are more equivocal. The two-tailed tests (i.e. tests for inequality of means) have low significance (p ~ .20 to .25). The one-tailed test of R/S (hatchery > natural) is marginally significant at the 10% level (p = .096), while the one-tailed Ln(R/S) is even less significant (p = .135). As discussed above, because of the assumptions inherent in the t-test, the Ln(R/S) is likely a better indicator of difference in mean survival.

Nonparametric Means Tests

The results of sign tests and Wilcoxon signed rank tests on the difference between mean hatchery and wild R/S and Ln(R/S) are presented in Tables 11-11 to 11-14.

Table 11-11: Nonparametric two-tailed paired difference tests on mean of R/S for Warm Springs.

Observations	13
Mean (Hatchery R/S - Natural R/S)	-1.0395
Std error of mean	0.5868
Number of diffs <= 0	9
Number of diffs > 0	4
Sign Test statistic (M)	-2.5
Pr >= |M|	.2668
Wilcoxon Signed Rank statistic (S)	-25.5
Pr >= |S|	.0803

Table 11-12: Nonparametric two-tailed paired difference tests on mean of Ln(R/S) for Warm Springs.

Observations	13
Mean (Hatchery R/S - Natural R/S)	-0.6930
Std error of mean	0.2872
Number of diffs <= 0	9
Number of diffs > 0	4
Sign Test statistic (M)	-2.5
Pr >= |M|	.2668
Wilcoxon Signed Rank statistic (S)	-29.5
Pr >= |S|	.0398

Table 11-13: Nonparametric two-tailed paired difference tests on mean of R/S for Imnaha.

Observations	9
Mean (Hatchery R/S - Natural R/S)	1.5222
Std error of mean	1.0701
Number of diffs <= 0	3
Number of diffs > 0	6
Sign Test statistic (M)	1.5
Pr >= |M|	.5078
Wilcoxon Signed Rank statistic (S)	10.5
Pr >= |S|	.2500

Table 11-14: Nonparametric two-tailed paired difference tests on mean of Ln(R/S) for Imnaha.

Observations	9
Mean (Hatchery R/S - Natural R/S)	0.5896
Std error of mean	0.4971
Number of diffs <= 0	3
Number of diffs > 0	6
Sign Test statistic (M)	1.5
Pr >= |M|	.5078
Wilcoxon Signed Rank statistic (S)	9.5
Pr >= |S|	.3008

For Warm Springs, the Wilcoxon tests give similar results to the t-tests, suggesting wild survival is different from hatchery survival, with the Ln(R/S) difference more significant (p = .04) than the R/S test (p = .08). The less powerful sign test is not significant. In the Imnaha comparison, the nonparametric tests for difference in population means are less significant than the t-tests, with p >= .25 for all nonparametric tests.

11.2.4 Discussion

Several hypotheses tests aimed at answering management questions directed at the efficacy of artificial propagation to halt and reverse the decline of wild salmon stocks were performed for two examples. Preliminary results of this study indicate that for the Warm Springs River, survival of progeny from naturally spawning fish is higher than that of hatchery offspring. Although in the Imnaha River, the mean survival of hatchery fish over the time period was greater than that of wild fish, the tests were equivocal and did not provide conclusive support for this difference. Variance tests suggest that in both rivers year-to-year survival of fish produced by hatchery spawning is more variable than that of naturally-produced fish. The 1985 Imnaha hatchery brood year was anomalous: because of a disease problem, Imnaha brood hatchery fish were not outplanted to the Imnaha River, but rather Lookingglass Creek, OR (R. Carmichael, pers. comm.). There was insufficient time to rerun the analysis excluding 1985 data for inclusion in this report. In addition, a reanalysis of the Imnaha data that includes estimates of numbers of fish harvested may be warranted. Data to enable this should be available shortly.

There are several cautions to be made about interpretations of the present results and results from any other hatchery/wild comparisons using these methods. The relatively short time series of data points for the examples examined introduce some complications. Using data from propagation programs with a longer record of data can address some of these problems. However, hatchery programs started in the more distant past are likely to have employed very different practices from those which are frequently proposed to help currently threatened populations. Variation in these practices could affect short and long term survival, perhaps in different directions. Also, survival of hatchery fish may have been different when there were more wild fish competing for resources, than it would be at present, with few wild fish (but more hatchery fish) left to compete.

One of the limitations of using a short time series of observations collected sequentially arises due to potential positive autocorrelation. Ignoring positive autocorrelation in a hypothesis testing context increases the probability of a Type 1 error (Bence 1995), meaning that significance is overestimated (p-value is underestimated). Autocorrelation in hatchery survivals could arise for several reasons. One might be that at the initiation of a propagation program, survivals might be low, and gradually increase due to learning and bug fixing. In fact, there is a sharp increasing trend evident in the Imnaha hatchery survival indices, which would be even more pronounced if not for the last year's brood (1990), which outmigrated in a poor water year.

Another consideration that may be relevant involves the objectives guiding management decisions about hatchery operation, and the kind of question about efficacy of supplementation programs that should be asked. Hatcheries may have or might produce additional adults without displacing wild fish, if wild spawning or rearing habitat is limiting or would be limiting if some fish were not taken into the hatchery to spawn. In that case, what a manager might want to know is the number of adult recruits that would be produced by a given number of spawners in the hatchery plus another number spawning in the wild, versus the recruits produced by letting all of the fish spawn in the wild. Observed wild R/S of a stock subject to supplementation is not necessarily a good indicator of how eggs from fish now being taken into hatchery would survive to adulthood if the spawners were allowed to spawn naturally, because of presumed density dependent mortality of spawners and juveniles. Letting all fish spawn in the wild would result in a lower wild R/S if compensation is operating.

The most important limitation, perhaps, is the difficulty of applying tests on a small number of hatchery programs to determine expected performance of proposed or recently initiated hatchery programs. Hatchery practices continue to evolve as new information is gathered; current and future hatchery practices may produce different survivals than past programs have. Each supplementation program will have unique circumstances and challenges. Confidence in conclusions reached in this kind of analysis should increase with the number of relevant hatchery/wild data sets examined.

Some of the limitations of the present study may be addressed through methods that could be employed in future analyses. To address the issue of potential habitat limitation (density dependence), an analysis where hatchery survival is compared to expected survival from the wild stock's estimated productivity curve, using the number of natural and wild spawners that brood year in place of the actual estimated number of wild spawners, can be performed. To retain information on annual variation in density-independent survival, rather than using the exact prediction of R/S for that invented S, the observed residual for realized R/S that year could be applied to the R/S derived from this hypothetical number of spawners.

The present analysis can be redone after testing and correcting for any autocorrelation in survivals in the manner suggested by Bence (1995). Other extensions that can be added include performing one-tailed versions of the nonparametric tests on means, and calculation of minimum detectable differences for t-tests. Another option that would increase the sample size (of the wild populations) is to include any stock-recruitment information from wild stocks before the propagation programs began. For Imnaha River naturally spawning chinook, this would add more than 30 brood years of data. Non-paired, unequal sample size hypothesis tests could then be performed. Drawbacks of this approach include losing the higher power of paired difference tests, with limited increases in power due to sample size, since the hatchery time series would remain the same length. In addition, possible violation of the assumption of equal variance in the two populations being compared necessary for the t-tests would mean that only nonparametric tests could be used.

11.2.5 Literature Cited

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11.3 Draft Pilot Study of Hatchery Influence on Wild Stock Survival

11.3.1 Introduction

This section is intended to present an example of an analytical approach to using data on hatchery programs and escapement and survival of naturally spawning salmon stocks to help test hypotheses about the impacts artificial propagation has had on those naturally spawning stocks. Readers are urged to comment on the appropriateness of the approach and methods.

11.3.2 Methods

The goal of this analytical approach is to estimate impacts on past wild stock survival of artificial propagation of salmonids. A regression approach, using an index of wild stock survival [ln(R/S)] as the dependent variable, is used. A number of potential independent variables intended to reflect the degree of hatchery influence have been proposed to use in the regression models for this analysis. These include both quantitative and categorical (or class) variables. They are:

Quantitative variables:
1. Naturally spawning escapement
2. Release number
3. Release number / index of wild fish (e.g., estimates of wild adult escapement)
4. Number of fish removed for hatchery brood stock / natural escapement
5. Size of hatchery fish at release (relative to size of co-occurring wild fish, if available)
6. Effective population size of hatchery spawners
7. Number of hatchery adults escaping to area of natural spawning
8. Fraction of naturally spawning population comprised of hatchery escapees
9. Egg-to-release survival of hatchery releases

Class Variables:
1. Brood stock source (indigenous or transplanted/mixed) or index of similarity (genetic or geographic) of donor stock to native stock - could be quantitative
2. Release method (volitional or forced)
3. Stage at release (yearling, subyearling)
4. Release location (some indicator of proximity to wild juveniles - could be quantitative)
5. Disease status / presence of known pathogens

Regression Analysis Approaches

Regression analyses using combinations of these variables could be performed in several different ways. One way is to regress a time series of recruit per spawner estimates for one wild stock against a number of these independent variables. This allows examination of effects of state changes in hatchery operations (i.e., a hatchery coming on line) within a stock. Another approach is to use regression to perform among-stock comparisons over the same time period, or similar time periods. If available data on several propagation programs and their affected stocks overlap for a sufficient number of years, hypothesis testing could be performed to attempt to partition the effects of different practices, as conditions over much of the life-cycle of the different stocks could be considered similar. This analysis could include stocks not influenced by hatchery fish or subject to very little impact (e.g. from occasional strays), at least in spawning, rearing, and tributary migration areas.

An extension of either the within- or among-stock approach would be to take into account differences in mainstem passage survival (Chapter 5’s mu) due to dams coming on line over time (within-stock) or difference in number of dams passed due to stream location (among-stock).

For this report, data on two stocks subject to hatchery influence are used to present an example of how the first approach (within-stock) might proceed. The stocks are Warm Springs River, Oregon, spring chinook and Imnaha River, Oregon, spring/summer chinook. The supplementation programs are described elsewhere in this chapter. Hatchery data were extracted from the StreamNet database (PSMFC 1996) by Dan Bouillon and Ian Parnell of ESSA Technologies. For this report, the independent variables examined were naturally spawning stock size, hatchery release numbers, and hatchery release numbers divided by natural escapement. Data on some of the other indicator variables has also been extracted from the StreamNet database; the availability of data on variables not included in that data base is uncertain, but will certainly vary among stocks. Naturally spawning escapement and recruitment data are from Beamesderfer et al. (1996).

11.3.3 Results

Examples of kinds and amount of data on hatchery releases in the vicinity of five different stocks, and the extent of the period for which data have allowed estimation of natural spawner R/S, are shown in Tables 11-15 to 11-19. Regressions of the response variable ln(R/S) for the two stocks were performed two different ways. The first used the GENMOD procedure in SAS (release 6.11 - SAS Institute 1996). This procedure fits a generalized linear model to the data using maximum likelihood estimation of the parameter vector. Two types of analyses were performed with the procedure. The first (Type 1) fits a sequence of models, beginning with only an intercept term and then adding one explanatory variable at a time in successive models. It allows estimation of the incremental explanatory power gained by adding each predictor variable in turn, results depending on the order specified. The other analysis (Type 3) fits the full model, and measures each predictor's explanatory power given that all other predictors are in the model. The results of this analysis do not depend on the order in which the independent variables are specified in the model.

The second regression method uses the SAS REG procedure. This procedure fits linear regression models by ordinary least-squares estimation. With this procedure, the effect on model fit of adding and subtracting variables from the model in different order, e.g. in forward, backward elimination, or stepwise fashion, can be determined.

In the tables described below for both stocks, the variable labels and the variables they refer to are:
YR = Brood year; REL = number of brood year hatchery fish released; S = Natural spawning escapement estimate; RPERS = Recruits per natural spawner; LN_RS = Natural logarithm of RPERS; RELPERS = REL / S.

For the Warm Springs River, S-R data are available beginning with brood year 1969, and include brood years up to 1990. The hatchery program began with brood year 1978.

Table 11-20 shows a matrix of coefficients for both Pearson and Spearman correlations, along with the p-values for the relation between variables. In addition to the variables mentioned above, brood year and R/S are included. Table 11-21 shows the results of the GENMOD regression for the Warm Springs. Tables 11-22 and 11-23 present the results of sample REG regressions for the Warm Springs.

S-R data on the naturally spawning Imnaha River fish are available from brood year 1949-1990, excluding 1951. The hatchery program began with the 1982 brood.

Table 11-24 shows a matrix of coefficients for both Pearson and Spearman correlation, along with the p-values for the relation between variables, for Imnaha. In addition to the variables mentioned above, brood year and R/S are included. Table 11-25 shows the results of the GENMOD regression for the Imnaha River. Tables 11-26 and 11-27 present the results of sample REG regressions for the Imnaha. Table 11-28 shows correlation matrices for the Imnaha for brood years 1982-90, the period after initiation of the supplementation program.

On the Warm Springs, release number, in combination with wild spawning escapement, appears to make a significant contribution in explaining the variability in wild ln(R/S), being negatively correlated with that index. In the Imnaha, none of the models fitted performs very well (maximum R-square = .17). There is a strong downward time trend in the response variable, and a strong upward time trend in release numbers (and number of releases per spawner) (Table 11-24). These trends are likely related to the increase in number of dams Imnaha fish have to traverse increasing with time, and the fact that the supplementation program was motivated by the consequent decline in numbers of spawners and survival. If only the years after initiation of the program are examined, there is no correlation between ln(R/S) and release numbers or releases per spawner evident (Table 11-28).

11.3.4 Discussion

The collinearity evident in the Imnaha independent variables and the effects of this apparent in the regression results point to a difficulty which will apply to within-stock time series analyses of many of the stocks with available data. Since many hatchery programs were launched in response to dramatically declining escapements, there will be significant downward time trends in the survival index, and release numbers are going to exhibit high negative correlation with natural spawning escapement and survival. Another limitation of the present analysis is that total release numbers have not been adjusted for their age at outplanting. That is, release numbers used here include yearling, subyearling, and indeterminate age releases. Therefore the implicit assumption is made that fingerling or fed fry releases that overwinter in-stream have the same impact as yearling releases. Whether they would have more or less effect on wild fish is uncertain; it is unlikely they have the same effect, though. For both the Imnaha, the regression results and correlation matrices suggest that release and release per spawner are redundant, and one or the other should be dropped in a parsimonious model. If this proves generally true when this analysis is extended to other stocks, only one or the other will be used, or alternatively, the number of releases divided by some non-varying measure of the size of the naturally spawning population, such as average escapement over the time period in question.

In addition to expanding the present analysis to include additional independent variables and other stocks, and performing among-stock regressions, several other methods may be worth trying. Interaction effects among independent variables could be examined for significance. Quantitative independent variables could be normalized by their time series mean, for within-stock analyses, or by an all-stock mean, for among-stock analyses. As mentioned above, trends in the response variable arising for reasons other than the value of the independent variables can be expected to be common. Also, in most cases, the long time-series of data available for the Imnaha will not be available. One of the limitations of using a short time series of observations collected sequentially arises due to potential positive autocorrelation. Ignoring positive autocorrelation in a hypothesis testing context about linear regression parameters increases the probability of a Type 1 error and leads to underestimation of confidence intervals on parameters (Bence 1995). Future regression analyses could incorporate testing and correction for autocorrelation in the manner suggested by Bence (1995).

11.3.5 References

Beamesderfer, R.C.P., H.A. Schaller, M.P. Zimmerman, C.E. Petrosky, O.P. Langness, and L. LaVoy. 1996. Spawner-recruit data for spring and summer chinook populations in Idaho, Oregon, and Washington. July 1996 Draft Documentation for PATH-Plan for Analyzing and Testing Hypotheses, Retrospective Analysis.

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Table 11-15: Summary of relevant data available from StreamNet on hatchery releases to Wind River. Wild R/S available for brood years 1970-90.

Table 11-16: Summary of relevant data available from StreamNet on hatchery releases to Klickitat River. Wild R/S available for brood years 1966-90.

Table 11-17: Summary of relevant data available from StreamNet on hatchery releases to John Day River. Wild R/S available for brood years 1959-90.

Table 11-18: Summary of relevant data available from StreamNet on hatchery releases to Warm Springs River. Wild R/S available for brood years 1969-90.

Table 11-19: Summary of relevant data available from StreamNet on hatchery releases to Imnaha River. Wild R/S available for brood years 1949-90, excluding 1951.

Table 11-20: Correlation matrices for Warm Springs data, b.y. 1969-1990.

6 'VAR' Variables: YR REL S RPERS LN_RS RELPERS						
Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 22						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.86942	0.14912	-0.48851	-0.55739	0.79637
	0	0.0001	0.5078	0.0211	0.007	0.0001
REL	0.86942	1	0.00315	-0.40433	-0.37463	0.89355
	0.0001	0	0.9889	0.062	0.0858	0.0001
S	0.14912	0.00315	1	-0.63009	-0.7234	-0.20963
	0.5078	0.9889	0	0.0017	0.0001	0.3491
RPERS	-0.48851	-0.40433	-0.63009	1	0.83692	-0.29862
	0.0211	0.062	0.0017	0	0.0001	0.177
LN_RS	-0.55739	-0.37463	-0.7234	0.83692	1	-0.19462
	0.007	0.0858	0.0001	0.0001	0	0.3854
RELPERS	0.79637	0.89355	-0.20963	-0.29862	-0.19462	1
	0.0001	0.0001	0.3491	0.177	0.3854	0
Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 22						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.82455	0.25127	-0.57724	-0.57724	0.73733
	0	0.0001	0.2593	0.0049	0.0049	0.0001
REL	0.82455	1	0.13255	-0.44941	-0.44941	0.89738
	0.0001	0	0.5565	0.0359	0.0359	0.0001
S	0.25127	0.13255	1	-0.77266	-0.77266	-0.10615
	0.2593	0.5565	0	0.0001	0.0001	0.6382
RPERS	-0.57724	-0.44941	-0.77266	1	1	-0.26632
	0.0049	0.0359	0.0001	0	0.0001	0.2309
LN_RS	-0.57724	-0.44941	-0.77266	1	1	-0.26632
	0.0049	0.0359	0.0001	0.0001	0	0.2309
RELPERS	0.73733	0.89738	-0.10615	-0.26632	-0.26632	1
	0.0001	0.0001	0.6382	0.2309	0.2309	0

Table 11-21: Results of Warm Springs GENMOD fit.

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	18	5.6160	0.3120
Scaled Deviance	18	22.0000	1.2222
Pearson Chi-Square	18	5.6160	0.3120
Scaled Pearson X2	18	22.0000	1.2222
Log Likelihood	.	-16.1971	

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT	1	2.8047	0.2880	94.8355	0.0001
S	1	-0.0015	0.0003	27.7723	0.0001
REL	1	-0.0000	0.0000	0.9384	0.3327
RELPERS	1	-0.0001	0.0005	0.0738	0.7859
SCALE	1	0.5052	0.0762		

NOTE: The scale parameter was estimated by maximum likelihood.

LR Statistics For Type 1 Analysis

Source	Deviance	DF	ChiSquare	Pr>Chi
INTERCEPT	16.6691	0	.	.
S	7.9461	1	16.2994	0.0001
REL	5.6349	1	7.5614	0.0060
RELPERS	5.6160	1	0.0737	0.7860

LR Statistics For Type 3 Analysis

Source	DF	ChiSquare	Pr>Chi
S	1	17.9612	0.0001
REL	1	0.9189	0.3378
RELPERS	1	0.0737	0.7860

Table 11.22: Results of REG regression on Warm Springs data, using adjusted R-square to select the model. AIC is Akaike's Information Criterion; BIC is Bayesian Information Criterion.

N = 22 Regression Models for Dependent Variable: LN_RS

Adjusted R-square	R-square	In	AIC	BIC	Variables in Model
0.62637344	0.66195692	2	23.96546	-20.75181	S REL
0.61173988	0.64871703	2	-23.12024	-20.14622	S RELPERS
0.60693507	0.66308720	3	-22.03914	-18.36013	S REL RELPERS
0.49947179	0.52330646	1	-18.40405	-16.98581	S
0.15754221	0.23777629	2	-6.07799	-7.25932	REL RELPERS
0.09736863	0.14035108	1	-5.43174	-6.05855	REL
-.01022958	0.03787659	1	-2.95413	-3.89654	RELPERS

Table 11-23: Results of REG procedure on Warm Springs data, using stepwise method to select the model.

Stepwise Procedure for Dependent Variable LN_RS

Step 1 Variable S Entered R-square = 0.52330646 C(p) = 7.46796577

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	8.72306062	8.72306062	1.96	0.0001
Error	20	7.94606397	0.39730320		
Total	21	16.66912459			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.42127799	0.27727144	30.29710318	76.26	0.0001
S	-0.00148410	0.00031673	8.72306062	21.96	0.0001

Bounds on condition number: 1, 1

Step 2 Variable REL Entered R-square = 0.66195692 C(p) = 2.06038660

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	11.03424238	5.51712119	18.60	0.0001
Error	19	5.63488221	0.29657275		
Total	21	16.66912459			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2.76590112	0.26949549	31.23931804	105.33	0.0001
S	-0.00148169	0.00027365	8.69471277	29.32	0.0001
REL	-0.00000091	0.00000033	2.31118176	7.79	0.0116

Bounds on condition number: 1.00001, 4.00004
All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable LN_RS

Step	Variable Entered / Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	S	1	0.5233	0.5233	7.4680	21.9557	0.0001
2	REL	2	0.1387	0.6620	2.0604	7.7930	0.0116

Table 11-24: Correlation matrices for Imnaha data, b.y. 1949-1990 (excl. 1951).

6 'VAR' Variables: YR REL S RPERS LN_RS RELPERS						
Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 41						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.57569	-0.56651	-0.43071	-0.48622	0.53436
	0	0.0001	0.0001	0.0049	0.0013	0.0003
REL	0.57569	1	-0.36001	-0.23423	-0.27498	0.85014
	0.0001	0	0.0208	0.1405	0.0819	0.0001
S	-0.56651	-0.36001	1	-0.1852	-0.1665	-0.36194
	0.0001	0.0208	0	0.2464	0.2982	0.0201
RPERS	-0.43071	-0.23423	-0.1852	1	0.84982	-0.22412
	0.0049	0.1405	0.2464	0	0.0001	0.1589
LN_RS	-0.48622	-0.27498	-0.1665	0.84982	1	-0.28014
	0.0013	0.0819	0.2982	0.0001	0	0.0761
RELPERS	0.53436	0.85014	-0.36194	-0.22412	-0.28014	1
	0.0003	0.0001	0.0201	0.1589	0.0761	0
Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 41						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.67681	-0.65261	-0.46568	-0.46568	0.67781
	0	0.0001	0.0001	0.0022	0.0022	0.0001
REL	0.67681	1	-0.5703	-0.33312	-0.33312	0.99854
	0.0001	0	0.0001	0.0333	0.0333	0.0001
S	-0.65261	-0.5703	1	-0.10592	-0.10592	-0.57584
	0.0001	0.0001	0	0.5098	0.5098	0.0001
RPERS	-0.46568	-0.33312	-0.10592	1	1	-0.33714
	0.0022	0.0333	0.5098	0	0.0001	0.0311
LN_RS	-0.46568	-0.33312	-0.10592	1	1	-0.33714
	0.0022	0.0333	0.5098	0.0001	0	0.0311
RELPERS	0.67781	0.99854	-0.57584	-0.33714	-0.33714	1
	0.0001	0.0001	0.0001	0.0311	0.0311	0

Table 11-25: Results of Imnaha GENMOD fit.

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	37	25.6196	0.6924
Scaled Deviance	37	41.0000	1.1081
Pearson Chi-Square	37	25.6196	0.6924
Scaled Pearson X2	37	41.0000	1.1081
Log Likelihood	.	-48.5371	

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Std Err	ChiSquare	Pr>Chi
INTERCEPT	1	1.1992	0.2521	22.6317	0.0001
S	1	-0.0003	0.0002	4.3499	0.0370
REL	1	-0.0000	0.0000	0.5060	0.4769
RELPERS	1	-0.0006	0.0008	0.7270	0.3939
SCALE	1	0.7905	0.0873	.	.

NOTE: The scale parameter was estimated by maximum likelihood.

LR Statistics For Type 1 Analysis

Source	Deviance	DF	ChiSquare	Pr>Chi
INTERCEPT	30.9152	0	.	.
S	30.0582	1	1.1526	0.2830
REL	26.0739	1	5.8302	0.0158
RELPERS	25.6196	1	0.7206	0.3959

LR Statistics For Type 3 Analysis

Source	DF	ChiSquare	Pr>Chi
S	1	4.1343	0.0420
REL	1	0.5029	0.4782
RELPERS	1	0.7206	0.3959

Table 11-26: Results of REG regression on Imnaha data, using adjusted R-square to select the model. AIC is Akaike's Information Criterion; BIC is Bayesian Information Criterion.

N = 41   Regression Models for Dependent Variable: LN_RS

Adjusted R-square	R-square	In	AIC	BIC	Variables in Model
0.11691101	0.16106546	2	-12.77587	-10.22617	S RELPERS
0.11220901	0.15659856	2	-12.55814	-10.04110	S REL
0.10410072	0.17129317	3	-11.27878	-8.43729	S REL RELPERS
0.05485152	.07848023	1	-10.92631	-8.94033	RELPERS
0.05191390	0.07561605	1	-10.79908	-8.82551	REL
0.03512709	0.08337073	2	-9.14448	-7.13357	REL RELPERS
0.00279063	0.02772086	1	-8.72795	-6.95620	S

Table 11-27: Results of REG procedure on Imnaha data, using stepwise method to select the model.

Stepwise Procedure for Dependent Variable LN_RS

Step 1 Variable RELPERS Entered R-square = 0.07848023 C(p) = 4.14390066

	DF	Sum of Squares	Mean Squares	F	Prob>F
Regressions	1	2.42622894	2.42622894	3.32	0.0761
Error	39	28.48893218	0.73048544		
Total	40	30.91516112			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	0.74108127	0.14126840	20.10264508	27.52	0.0001
RELPERS	-0.00077881	0.00042734	2.42622894	3.32	0.0761

Bounds on condition number: 1, 1

Step 2 Variable S Entered R-square = 0.16106546 C(p) = 2.45664564

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	4.97936455	2.48968228	3.65	0.0355
Error	38	25.93579656	0.68252096		
Total	40	30.91516112			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	1.16729604	0.25924633	13.83734523	20.27	0.0001
S	-0.00033627	0.00017386	2.55313562	3.74	0.0606
RELPERS	-0.00108900	0.00044311	4.12236970	6.04	0.0187

Bounds on condition number: 1.150753, 4.603013

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable LN_RS

Step	Variable Entered / Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	RELPERS	1	0.0785	0.0785	4.1439	3.3214	0.0761
2	S	2	0.0826	0.1611	2.4566	3.7407	0.0606

Table 11-28: Correlation matrices for Imnaha data, b.y. 1982-1990

6 'VAR' Variables: YR REL S RPERS LN_RS RELPERS						
Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 9						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.75005	-0.6926	-0.52931	-0.47051	0.87844
	0	0.0199	0.0386	0.1428	0.2012	0.0018
REL	0.75005	1	-0.42319	-0.06677	0.06062	0.72073
	0.0199	0	0.2564	0.8645	0.8769	0.0285
S	-0.6926	-0.42319	1	0.06208	0.05975	-0.86748
	0.0386	0.2564	0	0.8739	0.8786	0.0024
RPERS	-0.52931	-0.06677	0.06208	1	0.95644	-0.18792
	0.1428	0.8645	0.8739	0	0.0001	0.6283
LN_RS	-0.47051	0.06062	0.05975	0.95644	1	-0.09928
	0.2012	0.8769	0.8786	0.0001	0	0.7994
RELPERS	0.87844	0.72073	-0.86748	-0.18792	-0.09928	1
	0.0018	0.0285	0.0024	0.6283	0.7994	0
Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 9						
	YR	REL	S	RPERS	LN_RS	RELPERS
YR	1	0.8	-0.63333	-0.4	-0.4	0.86667
	0	0.0096	0.0671	0.2861	0.2861	0.0025
REL	0.8	1	-0.58333	0.13333	0.13333	0.93333
	0.0096	0	0.0992	0.7324	0.7324	0.0002
S	-0.63333	-0.58333	1	0.15	0.15	-0.78333
	0.0671	0.0992	0	0.7001	0.7001	0.0125
RPERS	-0.4	0.13333	0.15	1	1	0
	0.2861	0.7324	0.7001	0	0.0001	1
LN_RS	-0.4	0.13333	0.15	1	1	0
	0.2861	0.7324	0.7001	0.0001	0	1
RELPERS	0.86667	0.93333	-0.78333	0	0	1
	0.0025	0.0002	0.0125	1	1	0

11.4. Discussion

The consensus of the Hatchery Evaluation Group appears to be that for the literature review of Section 11.1 to be useful in gauging the credibility of the hypotheses, the table format in this draft is inadequate. Instead, we propose preparing a short paper for each hypothesis. The papers would relate what the relevant evidence or conclusion is from each citation, or at least categorize the evidence by mechanism implied, for those hypotheses where more than one mechanism can bear upon on the effect in question. The papers would elaborate on the hypotheses, discuss the strengths and limitations of each citation, and draw conclusions on what the weight of literature evidence implies about the hypothesis.

Some of the hypotheses in Section 11.1, not addressed by analyses of Sections 11.2 and 11.3, may still be tested by quantitative data, in addition to literature evidence. For example, the hypothesis that hatcheries change salmon age structure could be tested with existing data on age-at-return for Columbia Basin stocks reconstructed for PATH, either by comparing stocks without direct hatchery influence to those with influence, or by comparing age data for a stock before initiation of a hatchery program to data from the period after the hatchery came on line.

The analysis in section 11.2. could be extended by adding more hatchery/wild data sets. Candidates include Priest Rapids Hatchery / Hanford Reach fall chinook (WA), Washougal Hatchery / Washougal River fall chinook (WA), and a number of Idaho stocks (see below). Some steelhead stocks in the Columbia Basin might also be of use. Most of these cases involve hatchery programs which included as broodstock fish that were produced in different streams or in areas of the stream different from the location of the hatchery and wild stock being tested. This will likely complicate interpretation of results obtained by extending the analysis to these stocks, since differences in survival between hatchery- and naturally-produced fish cannot be attributed unambiguously to differences in early life environment and hatchery practices. Instead, genetic differences between the founding hatchery broodstock and the naturally spawning population can be expected to contribute to survival differences. It may be worthwhile to search for relevant data sets from hatcheries and wild stocks outside of the Columbia Basin. Another extension (suggested below) is to perform the comparison on a broader scale, i.e., group hatcheries from a major tributary (e.g. the Snake) and compare overall performance to that of wild stocks from the same tributary.

It is unclear at present how much data on some of the potential predictor variables in Section 11.3 is available. Data not in the StreamNet database will have to be extracted from agency reports and personal communication with hatchery personnel. A ranking of the likely relevance and practicality of the proposed predictor variables might help narrow the search and save time. It is also unclear how sharply to segregate or aggregate release numbers based on categorical variables such as life stage at release and season of release. There are many permutations possible for most stocks, and analyzing all of them would take a great deal of time. This analysis should help provide evidence about some of the hypotheses in section 11.1.2; how many will be determined, in part, by how much data can be gathered on the various predictor variables.

Because of the preliminary and incomplete nature of the analyses, implications of findings for management decisions and conclusions regarding research, monitoring, and evaluation priorities implied by these analyses have not been considered. They will be discussed in the final version of this chapter.

Some comments from readers on the previous version of Chapter 11 have been received. There was insufficient time to respond to or incorporate the suggestions made. Some of them are excerpted below:

Section 11.1

The introduction should include a general overview of hatchery goals, objectives and rationale, and make a distinction between augmentation, mitigation, supplementation, and conservation objectives. Not all hatcheries were built to restore wild stocks, or to mimic them. The emphasis in Section 11.1 is on documented and potential effects of hatchery fish on wild fish without a clear distinction of how the hatcheries in the case histories have been operated.

To what extent and how can hatcheries mitigate for environmental factors that limit wild stocks, and at what risks? The American Fisheries Society at one time had a committee addressing the issue of appropriate roles for hatcheries in fisheries management, which may have produced a useful general framework (in *Fisheries* magazine?).

The potential interactions between hatchery and wild fish could change under different levels of productivity and production. For example, potential for food and spatial competition between wild and hatchery fish would be relaxed at low production levels, especially considering that hatchery fish presence in the system is short term. The emphasis of the questions changes as one moves from crisis management to recovery levels.

No M & E recommendations were made in this chapter. Numerous supplementation (RASP 1992) and hatchery (e.g., LSRCP) evaluations are on-going in the Basin, as well as the IHOT (integrated hatchery oversight team) audit of hatcheries, fish health monitoring, etc. Are there missing elements from these that could provide more comprehensive answers to the questions posed in 11.1?

Section 11.2

Potential additional hatchery stocks from Idaho (and brood years) include: Dworshak NFH (1981-1990); Kooskia NFH (1969-1990); Rapid River (1966-1990); McCall (1975-1990); Red River ponds (1979-1990); Crooked River satellite (1985-1990); Powell (1984-1990); Sawtooth (1981-1990); East Fork Salmon River satellite (1984-1990); and Pahsimeroi (discontinuous releases, 1968-1990).

Most potential hatchery stocks do not have paired wild (natural spawning) stock data, but the brood year progeny-to-parent ratios for Snake River hatcheries (as replicates within a group) could be compared with those of the seven wild index stocks from Chapter 3.